THE UNIVERSITY OF ARIZONA
College of Engineering

Thoughts on Teaching MBSE

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Prepared for: US Army DEVCOM AVMC S3I MBSE Forum
15 March 2023

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Contents

- Introduction to UA MBSE Course
- Teaching MBSE
- Active Learning Principles Applied to MBSE
  - Backwards Design
  - Flipped Classroom
  - Mental Models
  - Motivation
  - Assessment
- Notes for Improvement
- Advanced Topics
- Open Questions

- Introduction to UA MBSE Course
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- Open Questions

Introduction to UofA Course SIE 458/558 Model Based SE

taken from 'MBSE – Lecture 1'

- This class is intended to introduce you to the **value** and **practice** of Model Based Systems Engineering (MBSE)
  - It is only an introduction. You will not be "qualified" as a system modeler by taking this class.
- The **value** of MBSE:
  - Increased quality, relevance, and traceability of system engineering being performed
  - May extend well beyond the systems engineering organization
- The **practice** of MBSE relies on:
  - Language: The Systems Modeling Language (SysML) is the dominant language for MBSE.
  - Tool: You must use a SysML authoring tool in this class.
  - Methodology: You will incrementally apply MBSE techniques in modeling your individually-selected class project.
    NOTE: This class will be consistent with SIE 454/554
- To understand MBSE, you must build system models
  - Your modeling assignments will make up the bulk of your grade

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Teaching MBSE

- Successful MBSE requires systems engineering thinking
  - (systems thinking applied to engineering)
- Language/tool/method
  - SysML 1x has breadth (if not rigor) for entire SE lifecycle
  - Students can learn tools faster than instructors can teach them
    - Tool Helps availability for students that need them
  - Method: taught through conventions & staged goals/criteria
- Learning MBSE through building models
  - Working through an end-to-end project will illustrate SE better than pre-staged modeling problems.
- LMS as a learning environment
  - Calendar, announcements, lectures, assignments, discussions
  - Availability of deeper resources

Beginning MBSE Class Approach

Senior/graduate student, single semester (SIE 458/558)

- Individual, not team assignments
  - Need for consistency in understanding concepts
- Project-based assignments
  - Subject chosen by student, approved by instructor
    - Broad enough to exercise SE concepts, but do-able in one semester
  - Sensor-Control-Effector type systems tend to work well, software or hardware only systems tend not to work well.
  - Each modeling assignment builds on the previous one
- Cover the scope of MBSE
  - Concept through validation
  - Experience 4-Pillars of SysML (Structure, Behavior, Requirement, Parametric modeling)
  - Experience model query, requirements traceability, model cohesion
- LMS as a learning environment
  - Week-by-week modules, with checklist, lecture video, assignments
  - Mandatory discussion topics (open ended, thought provoking)
  - Availability of deeper resources for enthusiastic students
- Grade Recovery
  - Extra credit quizzes

Teaching MBSE

- Students benefit from a wide range of learning styles.
- It has been recommended that instructors incorporate a range of teaching styles in their classroom [1], [12].

Our UA MBSE course incorporates:

- Instructional
  - traditional classroom style to present terms and concepts
- Examples
  - present examples of application in other work
- Interactive demos
  - build a model in the classroom together
- Discussions
  - ask students to participate in discussions regarding a topic (e.g. the applicability of a particular modeling approach)
- Independent study
  - Allow students to work independently (alone or in groups) outside of the classroom

Teaching MBSE

Progressive assignments outline a typical systems engineering method

- Mission Need Statement
  - Free-form text
  - The basis for system requirements
- Modeling Assignment #1
  - Framing the system context & mission need
- Modeling Assignment #2
  - Elaborating system structure, requirements, behavior & analysis approach
- Modeling Assignment #3
  - Completing the design: interfaces, interactions, and requirement traceability.

Mission Need Statement

- Forces students to describe the problem or need, rather than the solution
- Some students may struggle with this… and that's OK
  - Concept/problem definition, system boundaries, user goals … rarely taught in most undergraduate engineering curricula

#	Name	Text	Refined By	△ Derived
1	1.1 Mission Need			
2	MNS1 Mission Need Statement	Low-Earth Orbit (LEO) spacecraft need to be able to generate enough power to support nominal operations while in sunlight, and when in eclipse.		
3	MNS1.2 Eclipse	Spacecraft need to be able to generate enough power to support nominal operations while in eclipse		MR2 While in Eclipse
4	MNS1.1 Sunlight	Spacecraft need to be able to generate enough power to support nominal operations while in sunlight		MR1 While in Sunlight
5	1.2 Mission Requirements			
6	MR1 While in Sunlight	The power generated by the spacecraft shall be greater than the power required for nominal operations when in sunlight	Provide Power	SR1 Generate Power from Sun
7	MR2 While in Eclipse	The power generated by the spacecraft shall be greater than the power required for nominal operations when in eclipse	Provide Power	SR2 Store Power in Batteries SR3 Provide Power from Batteries

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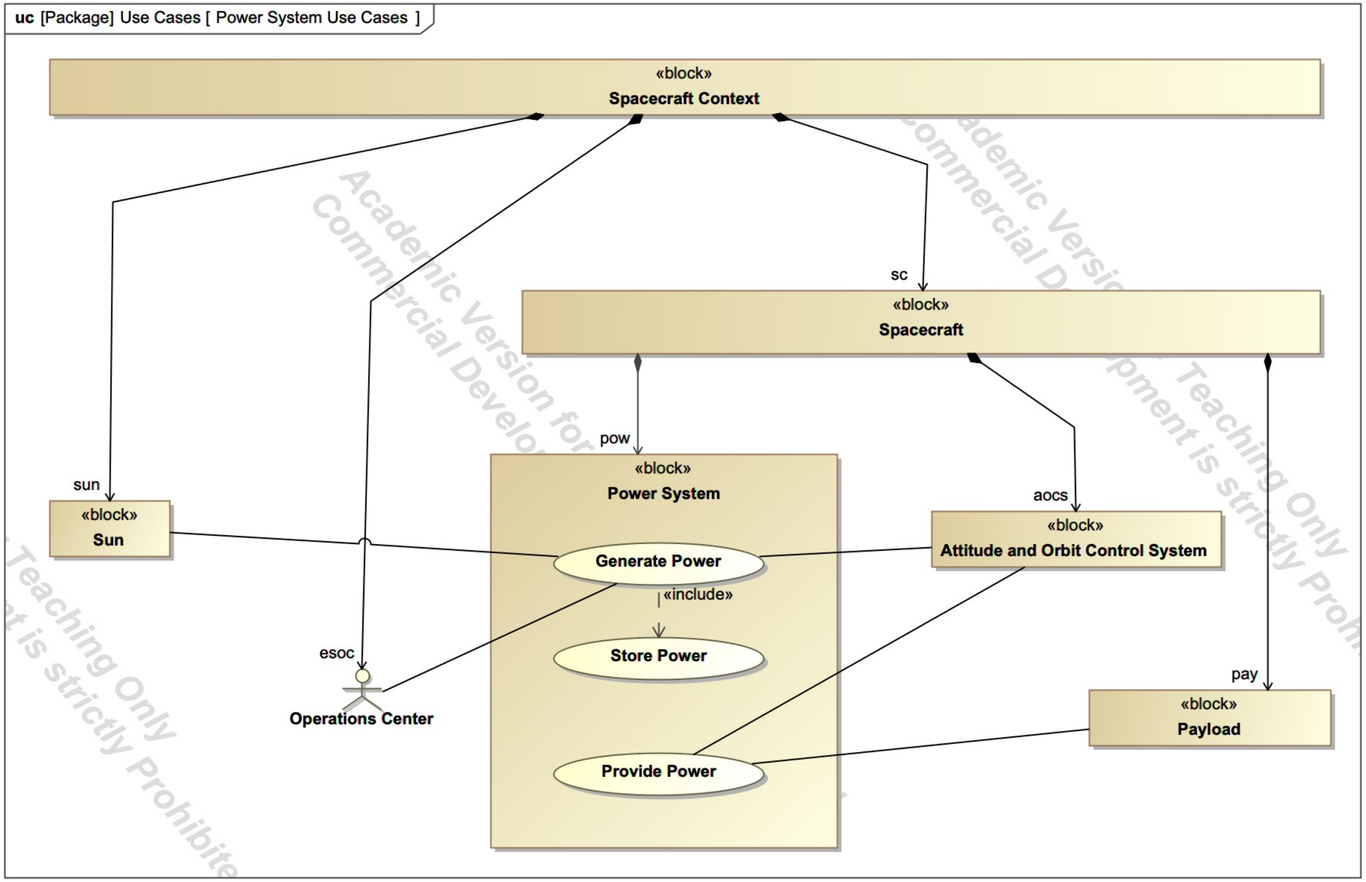
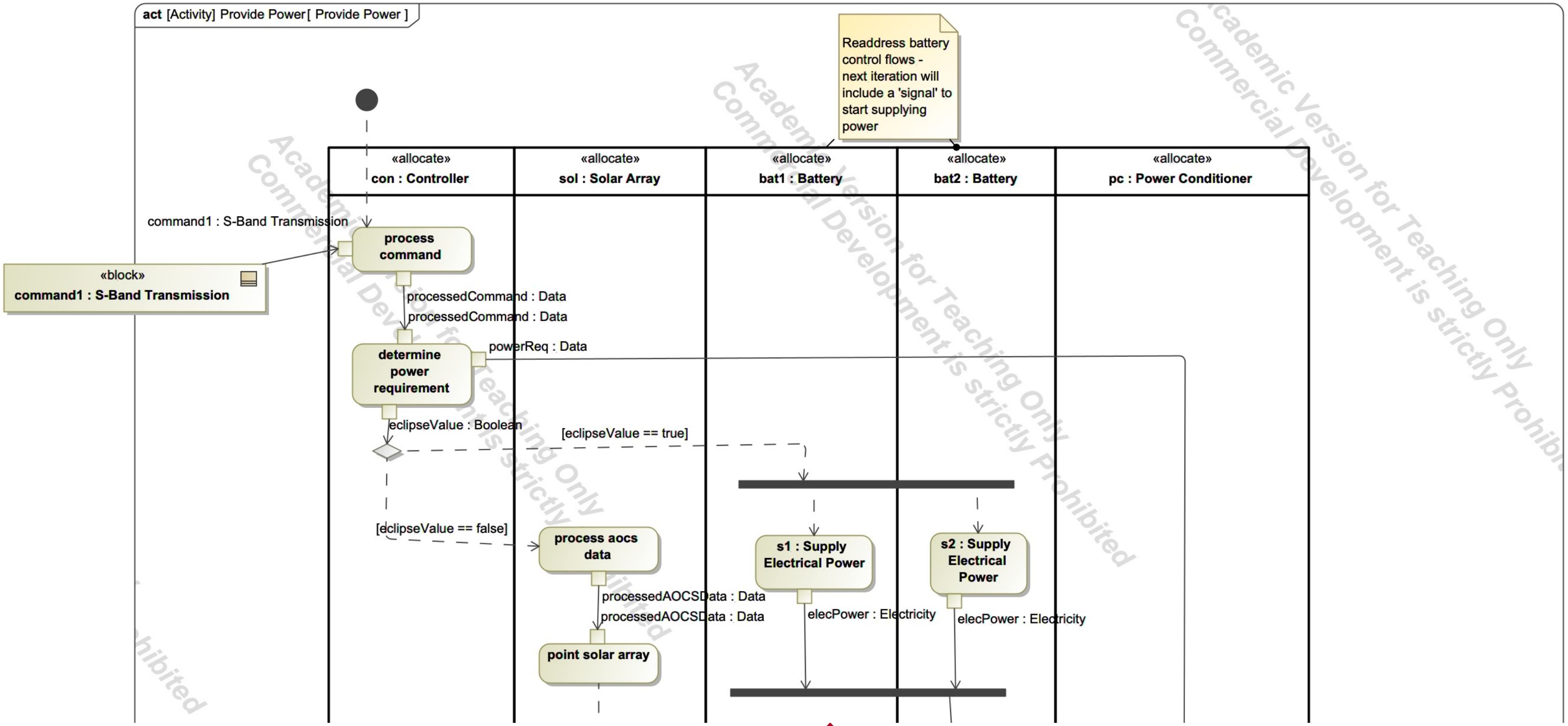
Modeling Assignment #1

- Model organization, system context (black box), mission need statement & requirements, mission level use case analysis

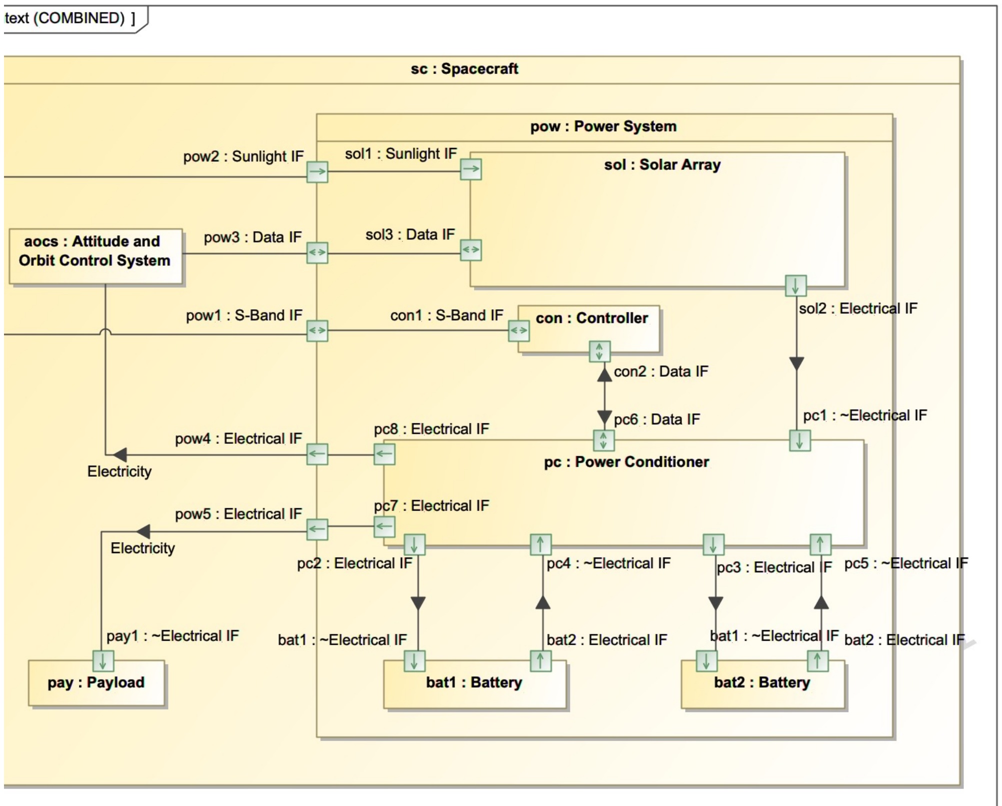


Modeling Assignment #2

- Continued model organization & consistency
- Attribute values & parametric models, use case activity modeling, internal system structure, system states & common behaviors, requirements linkage & updates



Modeling Assignment #3



- Cumulative model organization, requirement traceability, consistency
- Interactions/sequences, state & activity model updates
- Instance values & parametric analysis update
- Internal & external interface management, flow definition

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Backwards Design

- Combined effect of:
  - Learning outcomes
  - Assessments
  - Instructional materials / activities

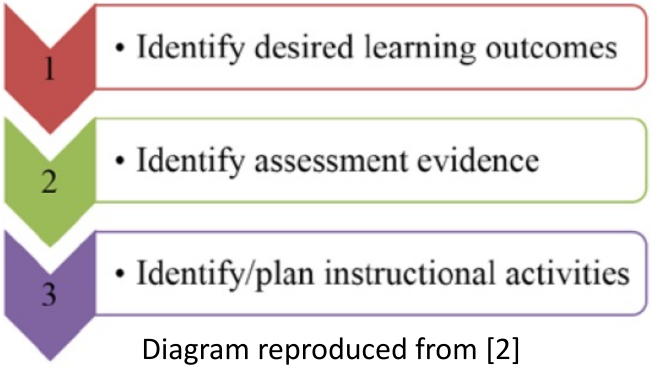


Diagram reproduced from [2]

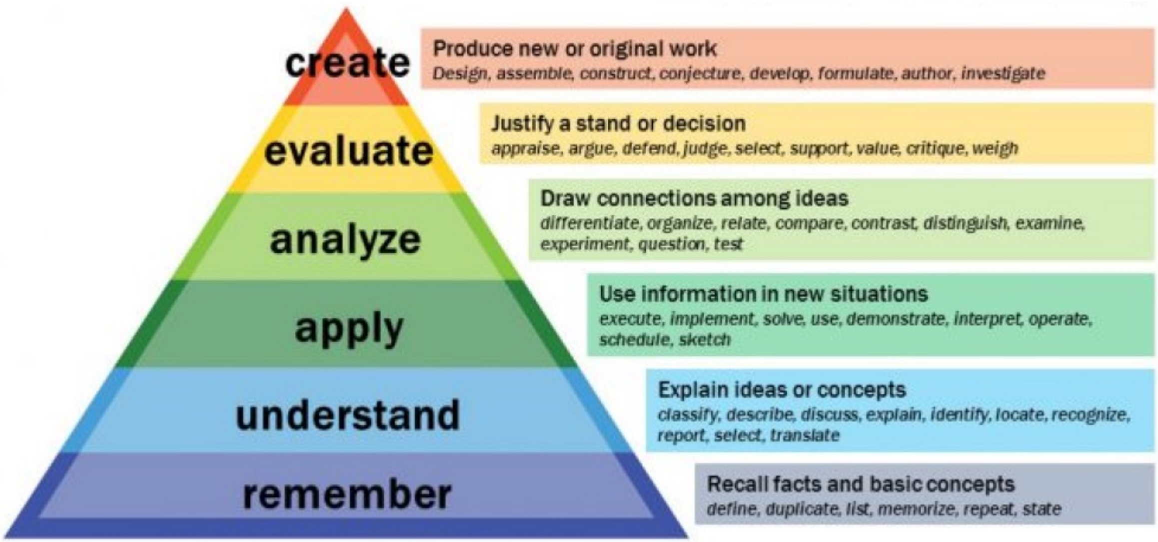
- Clear structure helps to motivate students [3]

Table 1: Abridged summary of backwards design approach to MBSE course

Learning Outcome	Assessment	Instructional Activities
Understand the value of MBSE	Discussion questions	Present examples from industry and academia
Practical Application of MBSE	Requirements model	Requirements elicitation, modeling demo
	Use case model	Use case elucidation, modeling demo
	Structural model	Black box and white box, modeling demo
	Behavioral model	Activities, states and sequences, modeling demo

Backwards Design

- Learning outcomes that span Bloom's taxonomy:



- Example from 'MBSE – Lecture 14: Activity Modeling':
  - Understand how activities use actions, nodes and flows to define behavior
  - Apply swimlanes to allocate behavior
  - Create an 'act' (schematic diagram) to model your system behavior

Diagram reproduced from [4]

Flipped Classroom

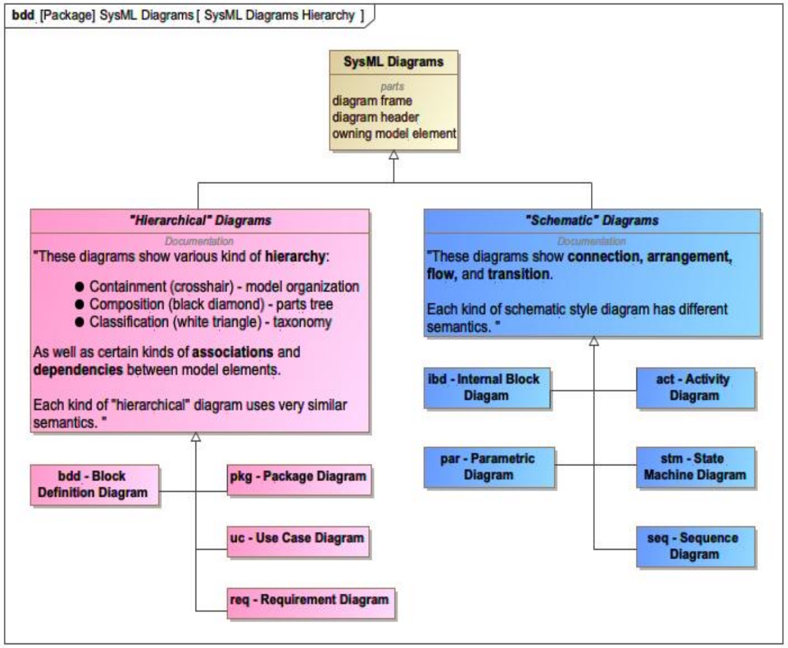
- Move easier tasks (introductory reading) outside of class.
- Save class time to work on more challenging problems / applications
- The most frequently reported advantage of the flipped classroom is the improvement of student learning performance [5].
- Major challenge is inadequate student preparation prior to class [5].

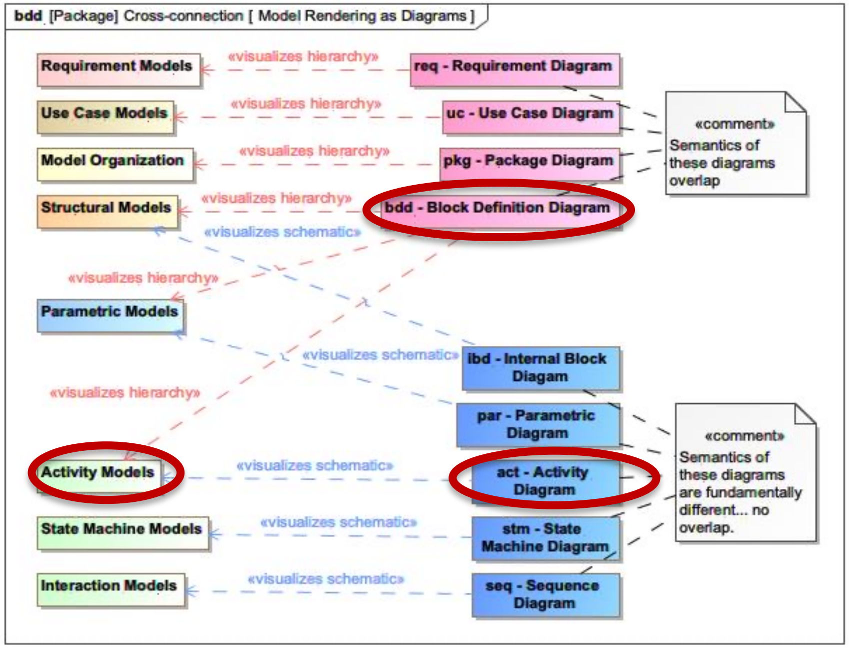
Table 2: Summary of our semi-flipped classroom approach

	Before Class	During Class	After Class
Traditional approach	-	Intro to concepts	Problems (as homework)
Flipped classroom approach	Intro to concepts	Problems	Further exploration
Our semi-flipped approach	Reading (Intro to concepts)	Intro to concepts Problems	Problems (as assignments)

Mental Models

- Diagrams (particularly simple diagrams) support students in factual learning [6].
- This approach can be applied to the course syllabus – it can help students to “grasp key information about a course” [7].
- We can use diagrams to support our textual syllabus.





Motivation

- Student motivation can be:
  - extrinsic (e.g. reward-based), or
  - intrinsic (from within) [8].
- It has been reported that intrinsic motivation leads to better long-term learning than extrinsic motivation [9].

> "Education is not the filling of a bucket, but the lighting of a fire"
>
> *W. B. Yeats*

- Techniques can be employed to foster intrinsic motivation [10], [11]:
  - Competence i.e. content pitched at the correct level
  - Community i.e. make the classroom a learning community
  - Autonomy i.e. allow students autonomy in their work
  - Authenticity i.e. provide an authentic audience for work
  - Purpose i.e. potential future roles, relevant current work
  - Lower Stakes i.e. encourage participation with low-stakes assignments
- Some examples to follow:

Motivation

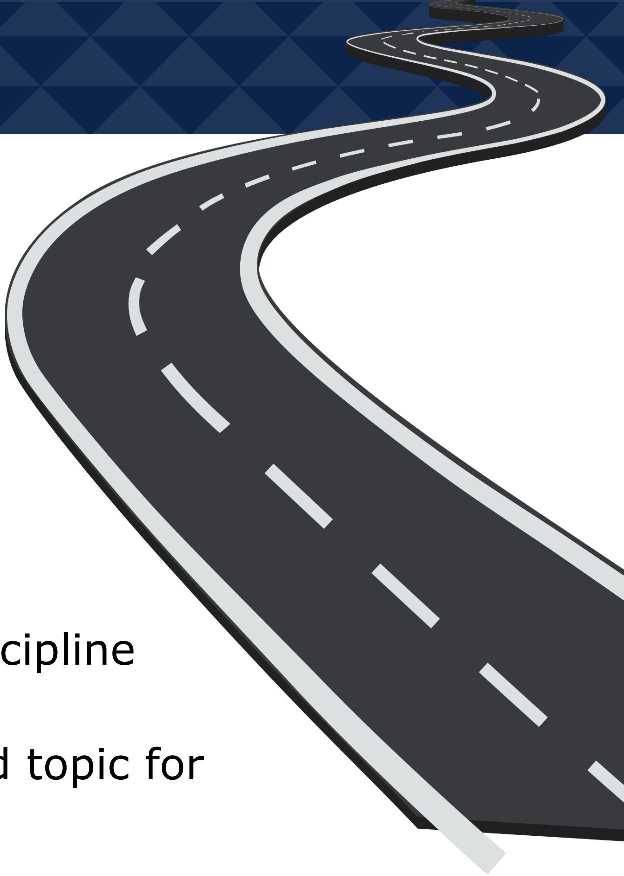
Community

- Discussion
  - Discussion forums to encourage students to discuss SE ideas with each other.
- Collaborative
  - Instructor-led demonstrations in which students put forward modeling suggestions.
- Peer feedback
  - An assignment in which students are tasked with grading models submitted by peers

Motivation

Authenticity

- Mirror Typical SE Process
  - Students work through an end-to-end SE process that mirrors a typical SE process
- Examples
  - Students are presented with examples to demonstrate that the concepts they are learning are used in academia and industry

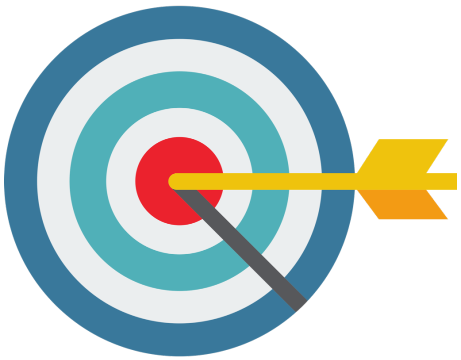


Motivation

Purpose

- SE Importance
  - The importance of Systems Engineering as a discipline can be an introductory topic.
  - The benefits / challenges of MBSE can be a good topic for a discussion question.
- Infamous Examples
  - Examples can be provided re: ‘when SE goes wrong…’
- Current Work
  - Examples of current work can be presented in each class.
  - i.e. “here is the current state-of-the-art to which you may wish to contribute”

Motivation



Lower Stakes

- Discussion Questions
  - Discussion questions are graded (low stakes).
  - They provide a low-risk incentive for students to contribute to the learning environment.
- Modeling Assignments
  - Three modeling assignments are graded over the course.
  - Each builds on the previous.
  - Students have the opportunity to correct previous mistakes for extra credit.
- Quizzes
  - Automated grading, multiple attempt
  - Good for grade recovery, while still demonstrating learning

Motivation

Autonomy

- Modeling Assignment Ownership
  - Students choose the subject of the modeling assignments.
  - Allows students to take ownership of their work.
  - Students are able to model something they are interested in.

Assessment

"People learn new material most effectively when they perceive a clear need to know it in order to solve a problem or meet a challenge" [12]

- Problem-Based Learning
  - Students given significant problem.
  - Students identify what they need to know
  - Students independently
  - Cognitive and motivational benefits in engineering [14], [16]
- Project-Based Learning (right)
  - Similar to Problem-Based Learning
  - Less instructional than Problem-Based Learning

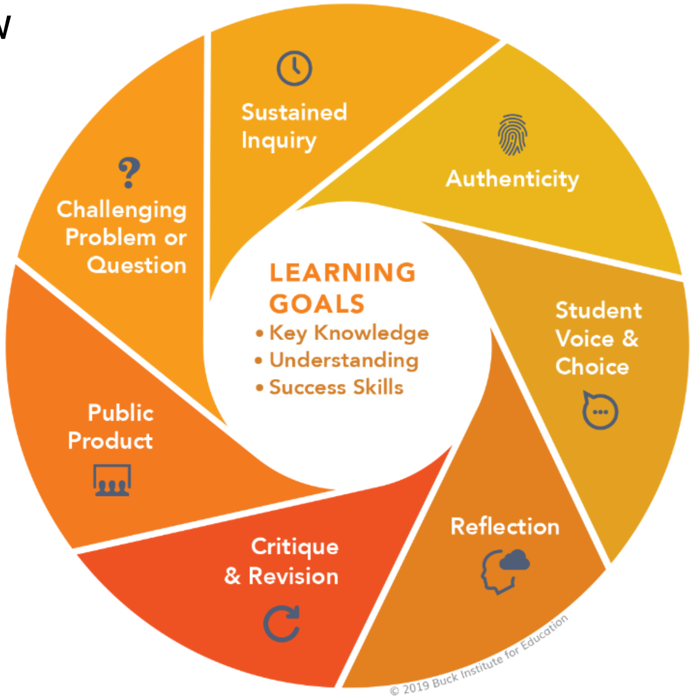


Diagram reproduced from [13]

Assessment

"The use of project-based learning as a key component of engineering programs should be promulgated as widely as possible, because it is certainly clear that [this] would be welcomed by students, industry and accreditors alike" [15]

Modeling Assignments - Overview

- Part 'Problem-Based', part 'Project-Based'
- Three modeling assignments
  - each building on the previous
  - MA1: Students define a problem that their system will address
  - MA2: Students define the black-box system
  - MA3: Students define the white-box system
  - MA4 (grad students only): Students critique peer submissions

Diagram reproduced from [13]

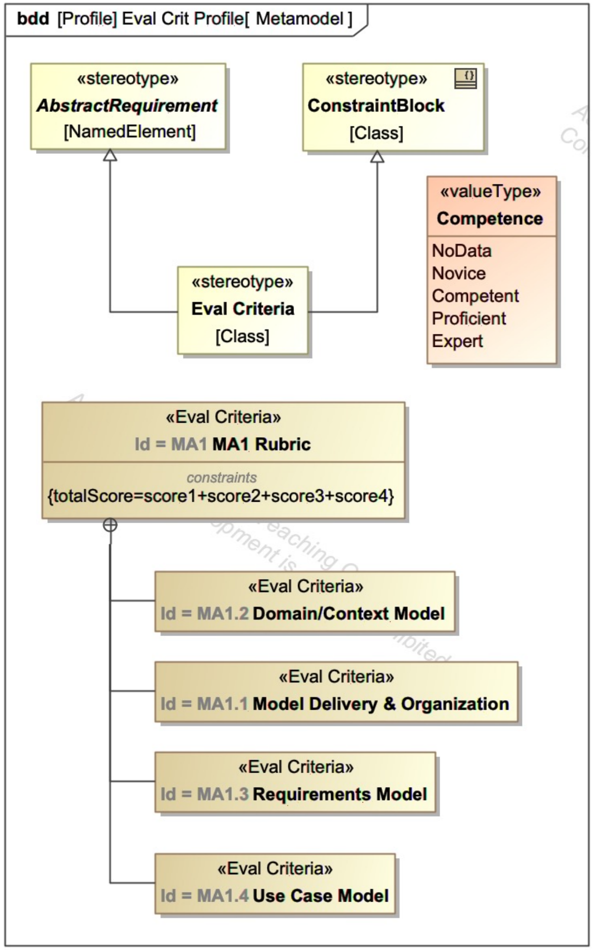
Assessment

Modeling Assignments - Grading Rubric Model

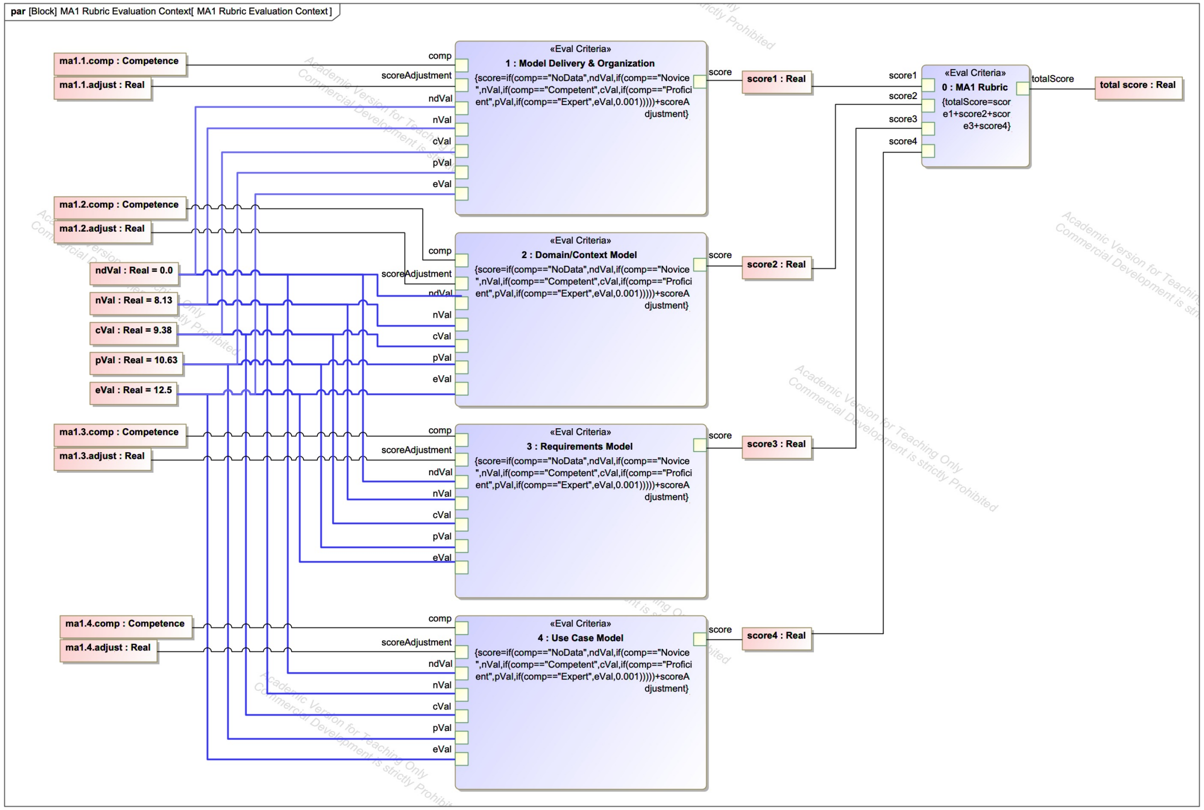
- Property-based requirement (rubric criteria with grade)
- «satisfy» relationship between rubric criteria and model element/diagram that meets the criteria
- Student imports rubric model into their project model, then describes how each criteria is met.
- Instructor reviews rubric table, provides detailed feedback, and executes parametric model for grading.
- Model review tables & matrices
  - Meta-chain queries are particularly useful

- Next step: server-based assessment
  - Collaboration environment (interactive wiki)
  - Report design & generation (pdf, web)
  - Metrics package & tracking

Assessment



Eval Criteria is a property-based requirement, rubric scores calculated using parametric model.



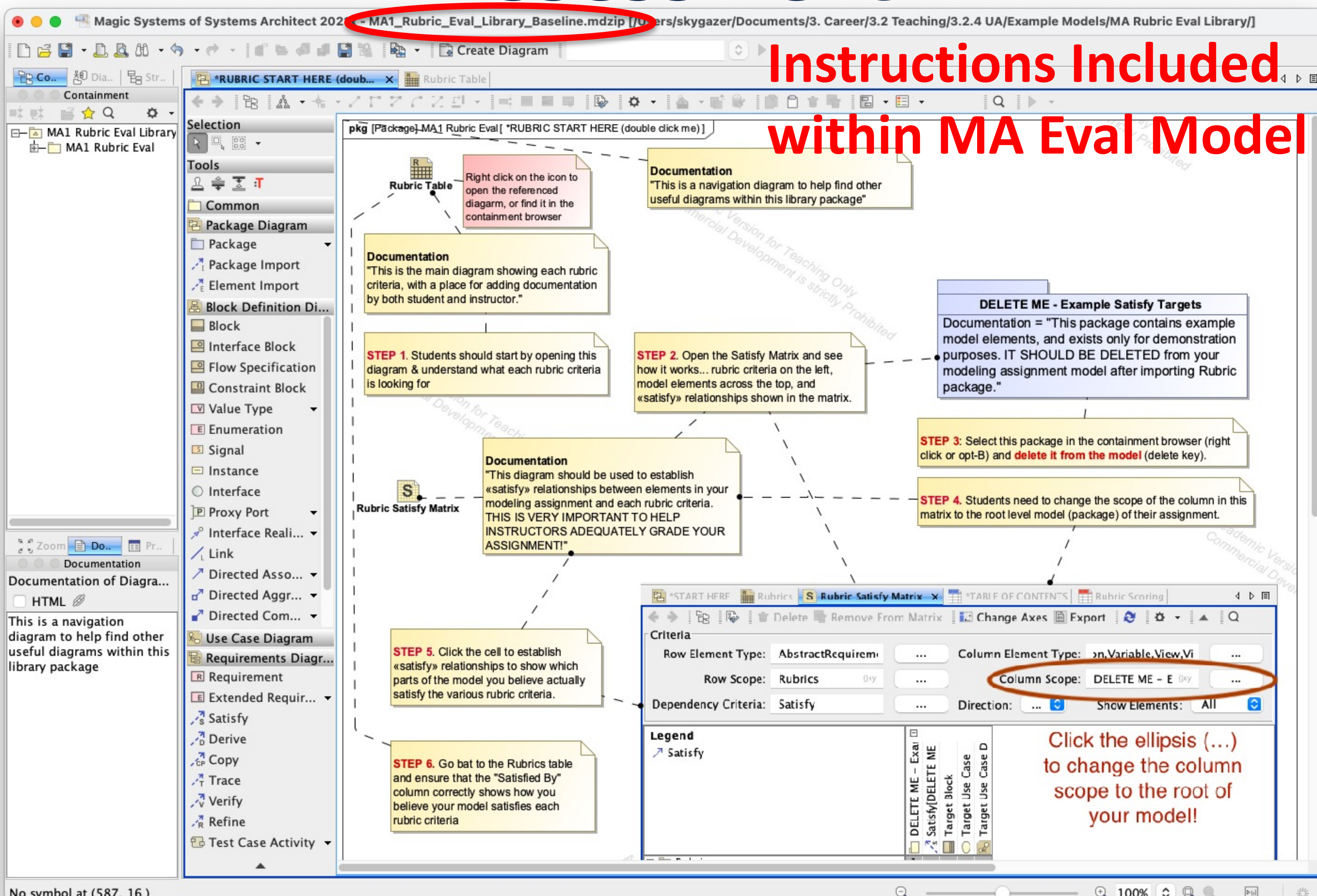
#	△ Name	total score	max score	ma1.1.comp	ma1.1.adjust	ma1.2.comp	ma1.2.adjust	ma1.3.comp	ma1.3.adjust	ma1.4.comp	ma1.4.adjust
1	ma1 eval1	44.64	50	Proficient	0	Proficient	0	Expert	0	Proficient	0.25

Assessment

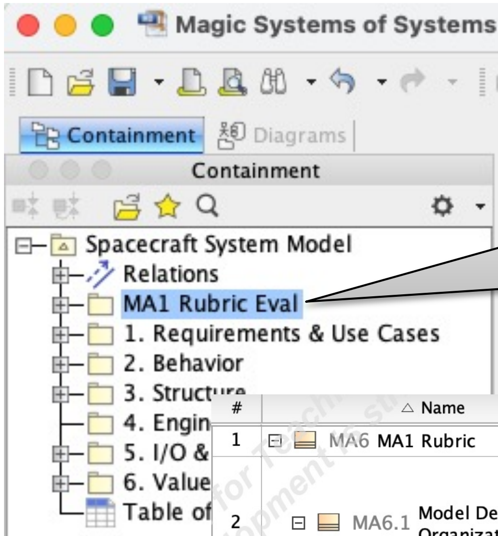
Modeling Assignment Rubric Eval Library

- Separate model of the grading rubric for each modeling assignment
  - Property-based requirement (rubric criteria with grade)
  - Parametric model for calculating grade
- Student imports rubric model into their project model, then describes how each criteria is met.
- Student creates «satisfy» relationship between rubric criteria and model element/diagram in their model that they that meets the criteria
- Instructor reviews rubric table once assignment submitted, provides detailed feedback, and executes parametric model for grading.

Assessment


Instructions Included within MA Eval Model
Magic Systems of Systems Architect 2022x - MA1_Rubric_Eval_Library_Baseline.mdzip [/Users/skygazer/Documents/3. Career/3.2 Teaching/3.2.4 UA/Example Models/MA Rubric Eval Library/]
Create Diagram
*RUBRIC START HERE (doub...
Rubric Table
Containment
MA1 Rubric Eval Library
MA1 Rubric Eval
Selection
Tools
Common
Package Diagram
Package
Package Import
Element Import
Block Definition Di...
Block
Interface Block
Flow Specification
Constraint Block
Value Type
Enumeration
Signal
Instance
Interface
Proxy Port
Interface Reali...
Link
Directed Asso...
Directed Aggr...
Directed Com...
Use Case Diagram
Requirements Diagr...
Requirement
Extended Requir...
Satisfy
Derive
Copy
Trace
Verify
Refine
Test Case Activity
Documentation
Documentation of Diagra...
HTML
This is a navigation diagram to help find other useful diagrams within this library package
pkg [Package] MA1 Rubric Eval[*RUBRIC START HERE (double click me)]
Rubric Table
Right click on the icon to open the referenced diagram, or find it in the containment browser
Documentation
"This is a navigation diagram to help find other useful diagrams within this library package"
Documentation
"This is the main diagram showing each rubric criteria, with a place for adding documentation by both student and instructor."
STEP 1. Students should start by opening this diagram & understand what each rubric criteria is looking for
STEP 2. Open the Satisfy Matrix and see how it works... rubric criteria on the left, model elements across the top, and «satisfy» relationships shown in the matrix.
DELETE ME - Example Satisfy Targets
Documentation = "This package contains example model elements, and exists only for demonstration purposes. IT SHOULD BE DELETED from your modeling assignment model after importing Rubric package."
STEP 3: Select this package in the containment browser (right click or opt-B) and delete it from the model (delete key).
Rubric Satisfy Matrix
Documentation
"This diagram should be used to establish «satisfy» relationships between elements in your modeling assignment and each rubric criteria. THIS IS VERY IMPORTANT TO HELP INSTRUCTORS ADEQUATELY GRADE YOUR ASSIGNMENT!"
STEP 4. Students need to change the scope of the column in this matrix to the root level model (package) of their assignment.
STEP 5. Click the cell to establish «satisfy» relationships to show which parts of the model you believe actually satisfy the various rubric criteria.
STEP 6. Go bat to the Rubrics table and ensure that the "Satisfied By" column correctly shows how you believe your model satisfies each rubric criteria
Rubric Satisfy Matrix
Delete
Remove From Matrix
Change Axes
Export
Criteria
Row Element Type: AbstractRequirem
Column Element Type:
Row Scope: Rubrics
Column Scope: DELETE ME - E
Dependency Criteria: Satisfy
Direction:
Show Elements: All
Legend
Satisfy
Click the ellipsis (...) to change the column scope to the root of your model!
No symbol at (587, 16)
100%

Assessment



Rubric Eval model imported into student submission

Rubric Table provides specific eval criteria

Student can indicate how they believe criteria has been met

5 levels of competence evaluated for each topic

#	Name	Text	Documentation	Satisfied By
1	MA6 MA1 Rubric	Framing the system context and mission need.	Student comments provided	
2	MA6.1 Model Delivery & Organization	The model has successfully been delivered to the instructor, is well organized, and intuitive to navigate. To count for grading, each of the following criteria must have «satisfiedBy» relationships to elements in your model.	This model is well organized. See table of contents for intended contents of each package	Table of Contents
	MA6.1.1 No Data	Files not submitted or can't be opened.	This model submitted.	
	MA6.1.2 Novice	All files submitted can be opened.	This model can be opened in Cameo21x.	Table of Contents
	MA6.1.3 Competent	Model seems organized but method is unclear or inconsistent.	Basic structure of numbered packages.	Table of Contents
	MA6.1.4 Proficient	Model organization is obvious, unambiguous, and consistently applied.	Each package has a description of expected contents.	Table of Contents
	MA6.1.5 Expert	Table of contents or Navigation aids provided.	TOC provided	Table of Contents
8	MA6.2 Domain/Context Model	The model successfully represents the context or domain in which your project system will exist.To count for grading, each of the following criteria must have «satisfiedBy» relationships to elements in your model.	Context for the power system is provided by both the spacecraft itself and the spacecraft context.	Spacecraft Context Spacecraft
14	MA6.3 Requirements Model	The model successfully states the mission need and decomposes it into mission requirements. To count for grading, each of the following criteria must have «satisfiedBy» relationships to elements in your model.	Mission Needs Statement (MNS) broken down into Mission Requirements, from which System Requirements are derived.	Power System Requirements Table
20	MA6.4 Use Case Model	The model successfully demonstrates a concise set of stakeholder goals for you system in its context, as expressed by use cases. To count for grading, each of the following criteria must have «satisfiedBy» relationships to elements in your model.	3 Use Cases are provided, and contextualized via use case diagram. Use case descriptions provided in documentation field, as shown in Use Case Table	Power System Use Cases Use Case Table

Assessment

Modeling Assignments – Closing the Loop

- "Encouraging self-reflection on strengths and weaknesses is an essential factor in training reflective practitioners" [17].
- Students have the opportunity to implement feedback
  - i.e. correct / improve subsequent modeling assignments.
  - Students receive extra credit for doing this.
- Benefits of *Formative Feedback* [18].

Discussion Questions

- As previously mentioned, low-stakes points are available.
  - Discussion questions incentivise participation with low risk.

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Notes for Improvement

- Greater elicitation of prior knowledge
- More examples of real-world applications / projects
- Collaboration (e.g. group projects with individual responsibilities)
- IDE, DE Factory

Diagram reproduced from [13]

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Advanced Topics

- Model information sharing
  - Document/web generation & understandability
  - Interactive portals & access to information
- Model metrics, maturity, and trend analysis
  - MOE, MOP, KPP, TPM, quality
- Model based design & readiness reviews
  - Collaborative & non-collaborative environments
  - Review readiness metrics
- Integrated development environments & program needs
  - System-Mechanical (MCAD), System-Software (CASE), System-Electrical (ECAD) model interfaces
  - Role of System model in Integration, Verification & Support
  - Role of System model in Reliability, Maintainability, Availability & Safety
- Closed-loop whole-system trade & optimization studies

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Is Object-Oriented Necessary?

- Yes: SysML 1.x is (mostly) a strongly-typed language.
  - Classifer (e.g. Block) has property (e.g. part property, value property)
    - **Properties have no properties themselves**… only inherit from type/called classifier
  - System context established via properties of a higher-level classifier (how is the Block ***used***?)
- No: SysML 2.x typing is ***optional***
  - Usage focused: modeling can be done with parts, actions, requirements, interfaces, without definitions. Properties can have their own properties and be reused directly in other properties.
  - Object focused: definitions (e.g. PartDef) can establish "Black Box" characteristics, for specification or tradeoff analysis
- So, should teaching MBSE using SysML 2 include Object Oriented principles or not?
  - It has been a stumbling block for many non-software students.

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